

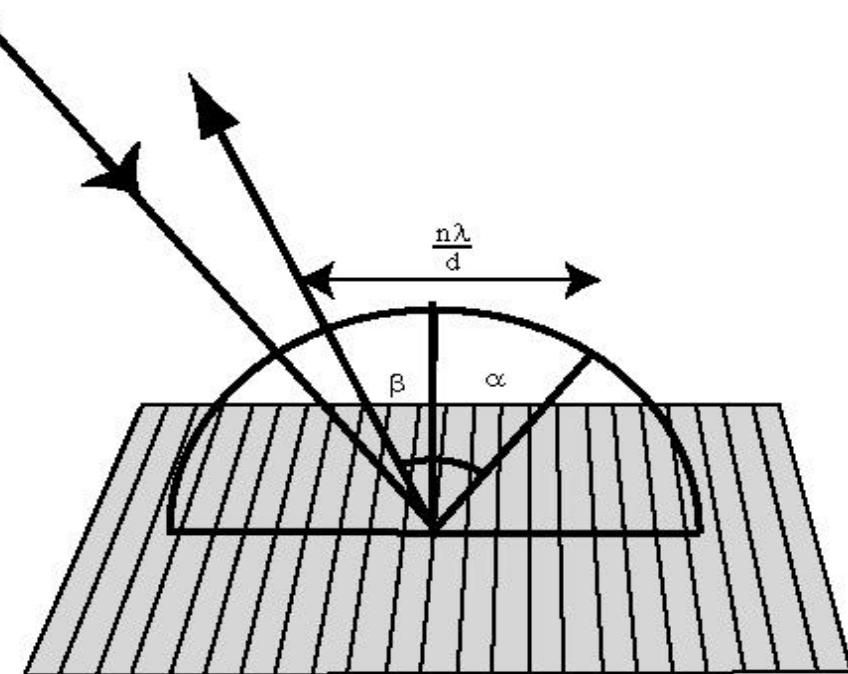
The Off-Plane Option Study Results Potential Capabilities

Webster Cash

University of Colorado

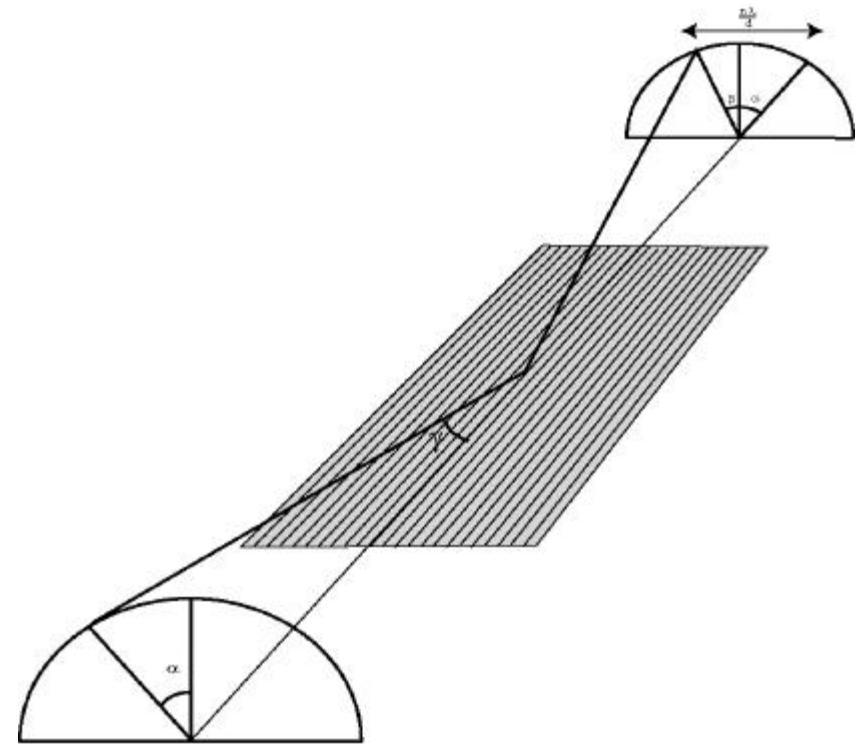
In-plane Mount

$$\sin a + \sin b = \frac{nL}{d}$$

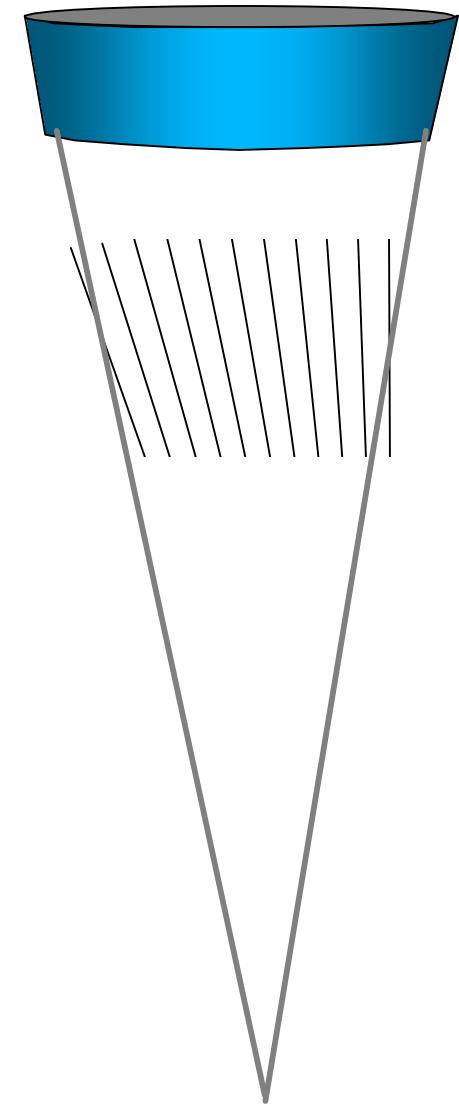
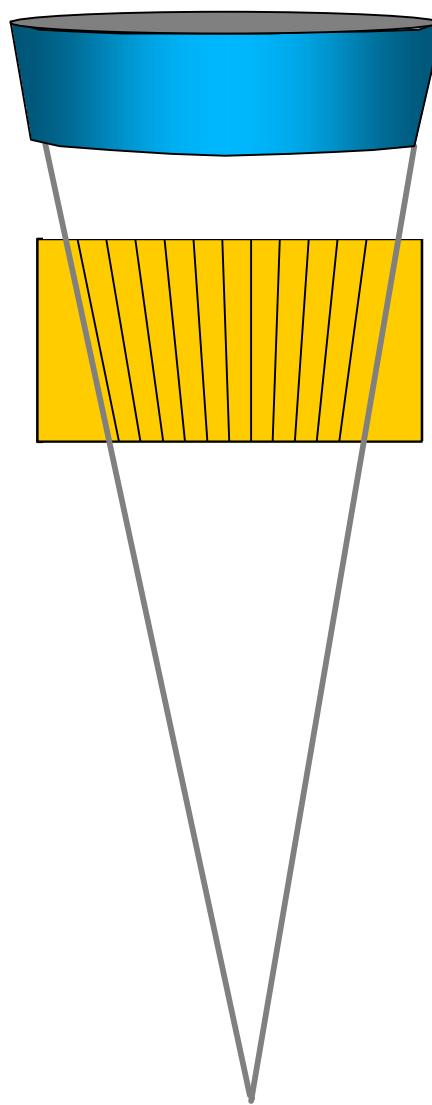
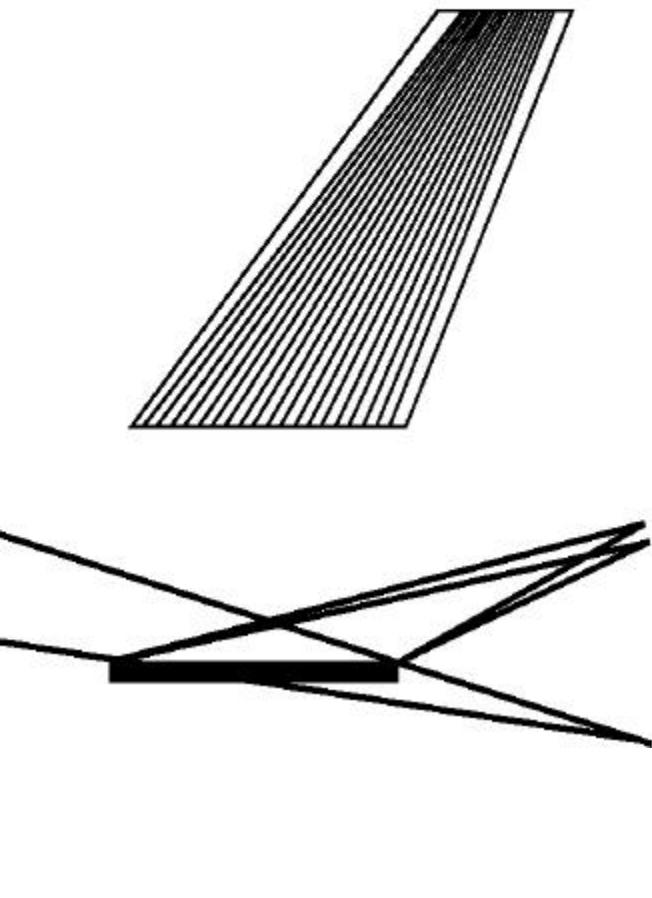


Off-plane Mount

$$\sin a + \sin b = \frac{nL}{d \sin g}$$



Radial Groove Gratings



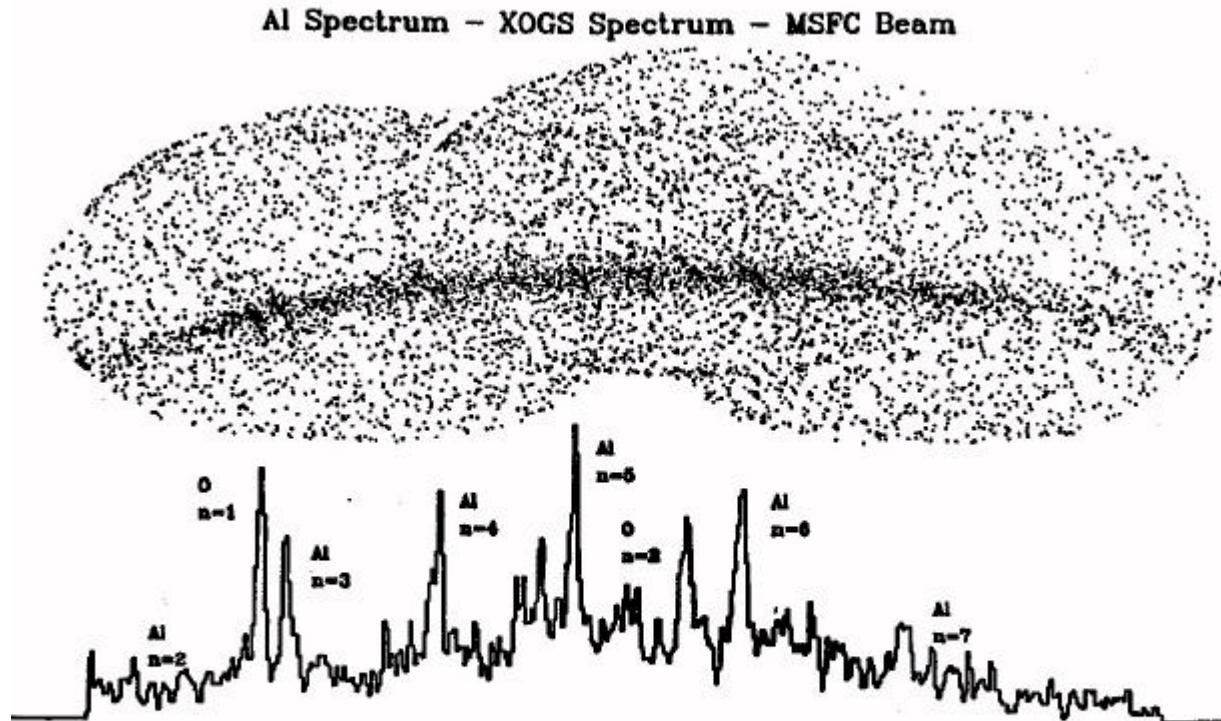
Off-plane Resolution

$$R = \frac{(\sin \mathbf{a} + \sin \mathbf{b}) \sin \mathbf{g}}{B \cos \mathbf{a}}$$

At typical values of off-plane angles and 15" telescope resolution
R ~ several hundred ? thousand

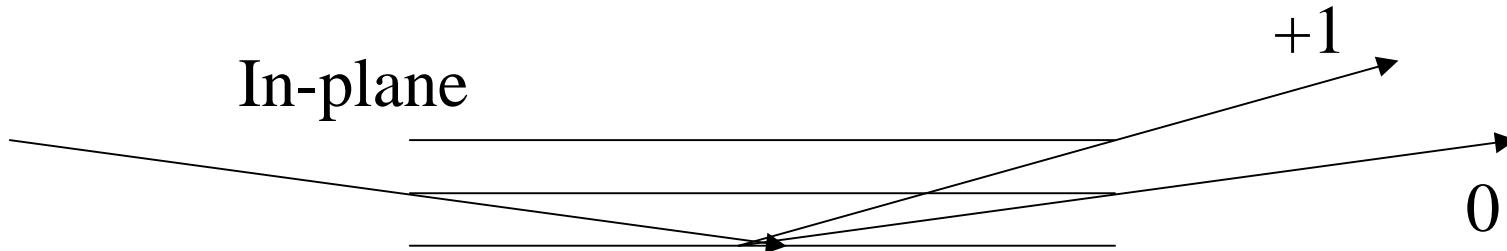
Sub-Aperturing improves it further

An Off-plane X-ray Spectrum



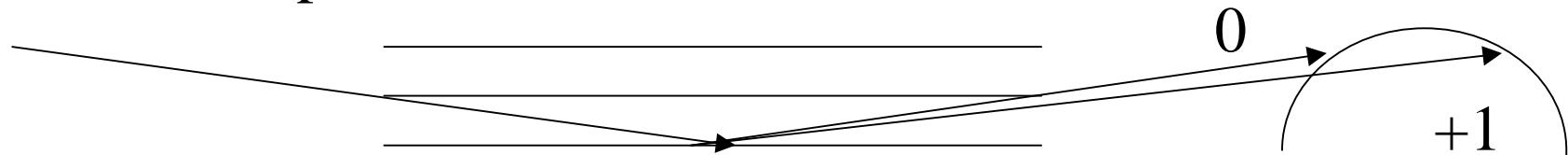
Spectrum from Al target shows Al $\text{K}\alpha$ ($\lambda=0.34$, $E=1.4\text{keV}$) in orders $n=2$ through $n=7$. Contamination from O $\text{K}\alpha$ ($\lambda=0.36\text{\AA}$, $E=0.525\text{keV}$) is also clearly present in first and second orders. Note that the blaze function is about 20 deg. in azimuthal angle. This spectrum was obtained by the XOGS spectrograph in the beam facility at Marshall Space Flight Center using a 3800 g/mm grating array in the off-plane mount. The signal in the sum of orders 3 through 6 is about 40% of the incident signal. With a CCD these orders can be recombined without loss of signal or resolution.

Packing Geometry



Central grating must be removed.
Half the light goes through.

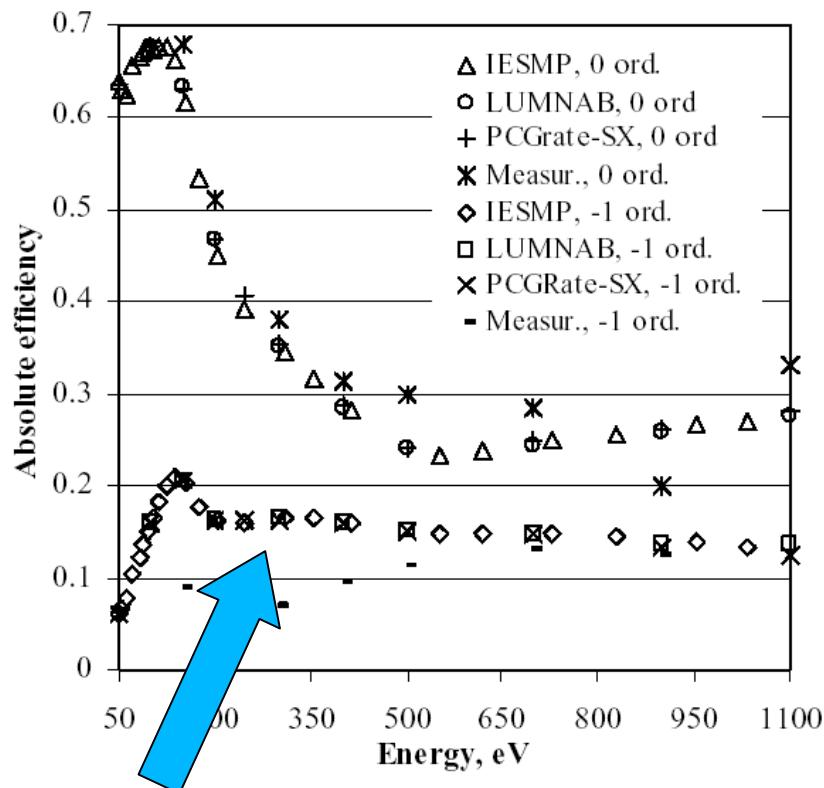
Off-plane



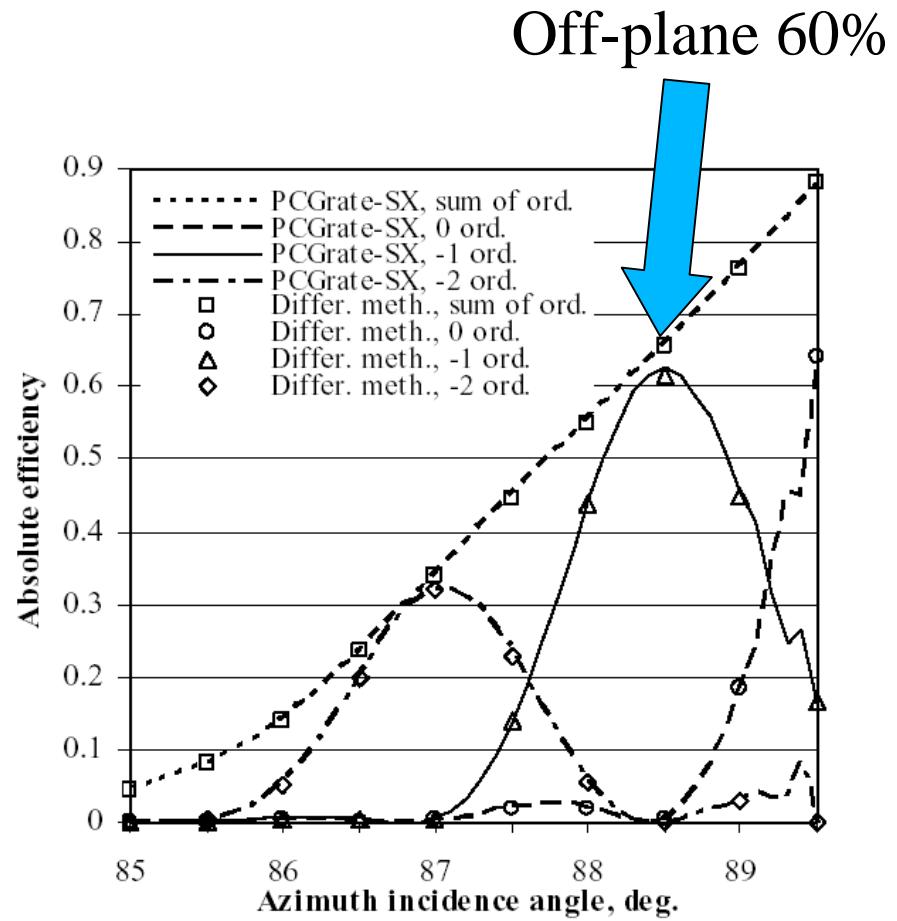
Gratings may be packed optimally

Throughput

L. Goray -- SPIE 2003



In-plane 17%

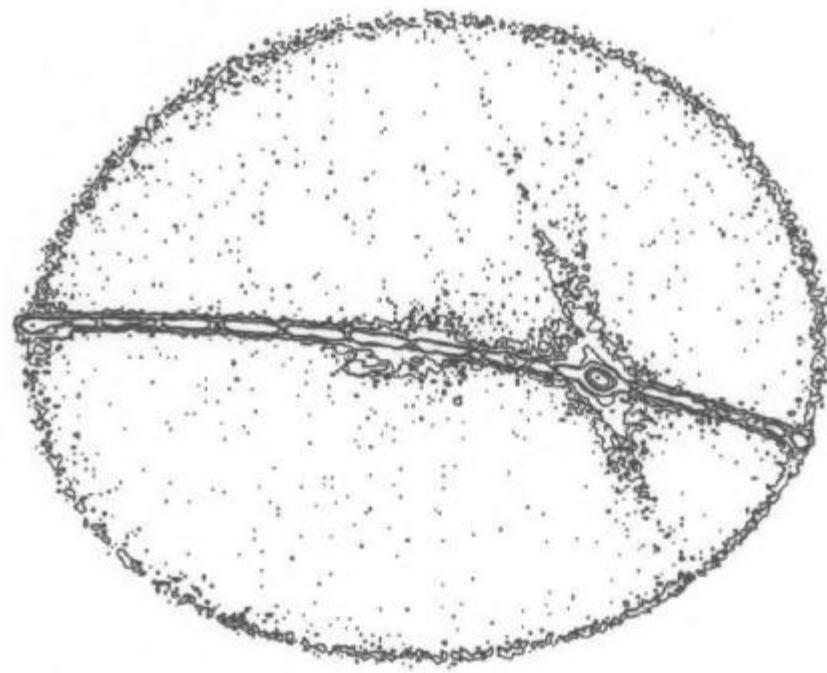
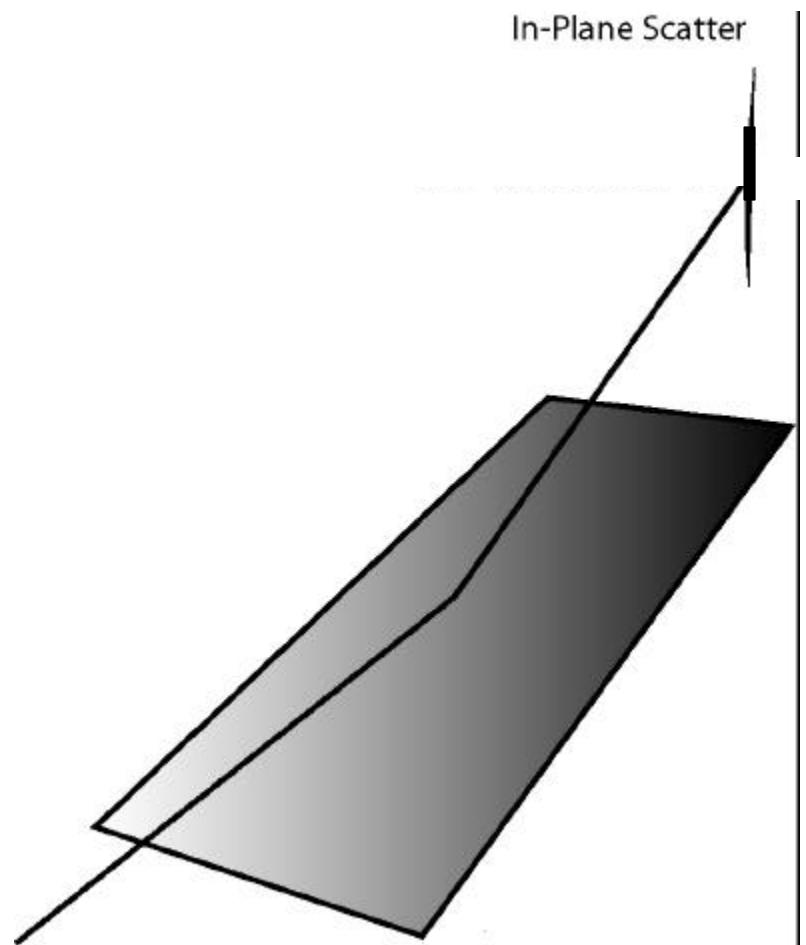


Off-plane 60%

Internal Structure of Telescope

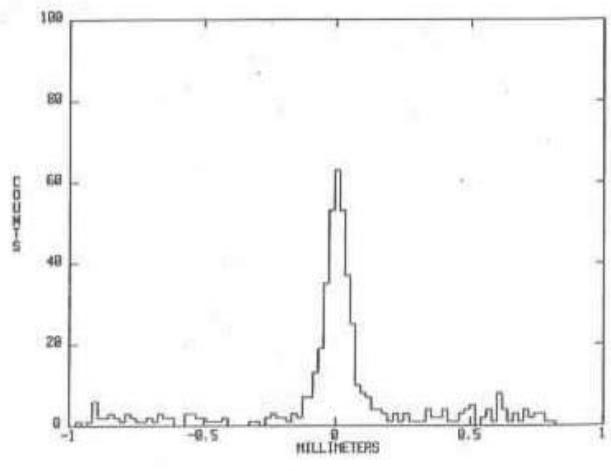
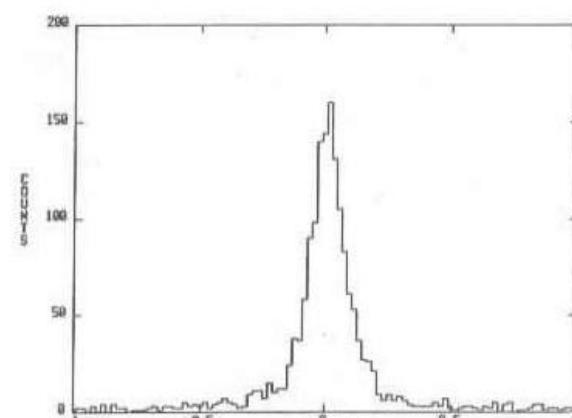
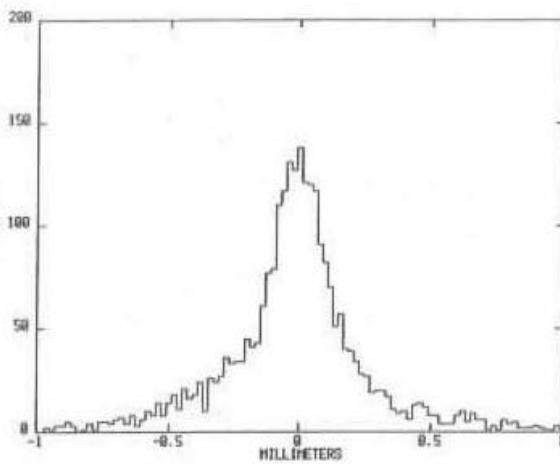
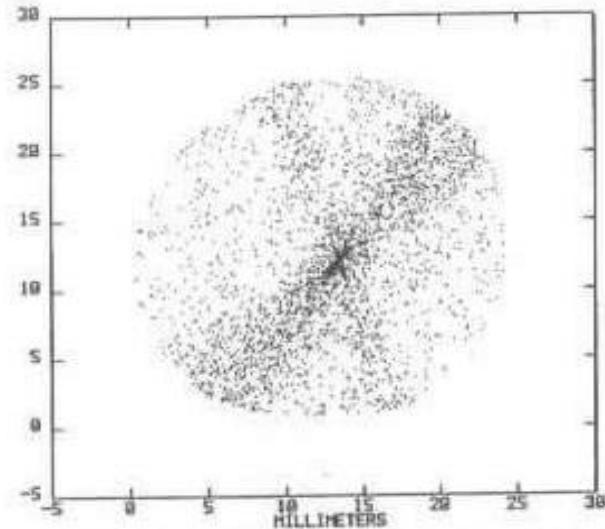
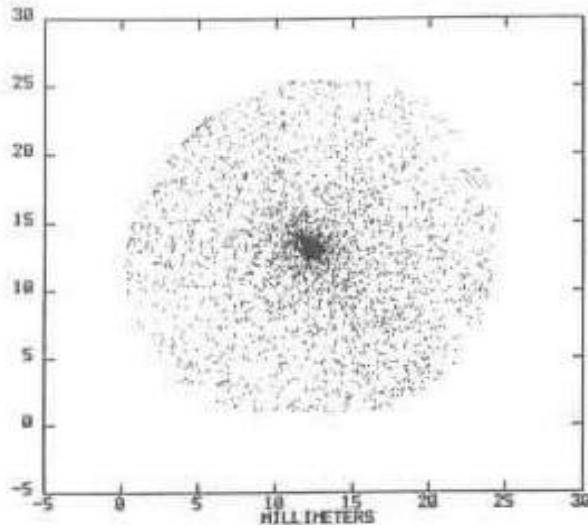
lur Favors Dispersion in Off-plane Direction

Spectral line of HeII 304Å
displaying In-plane scatter

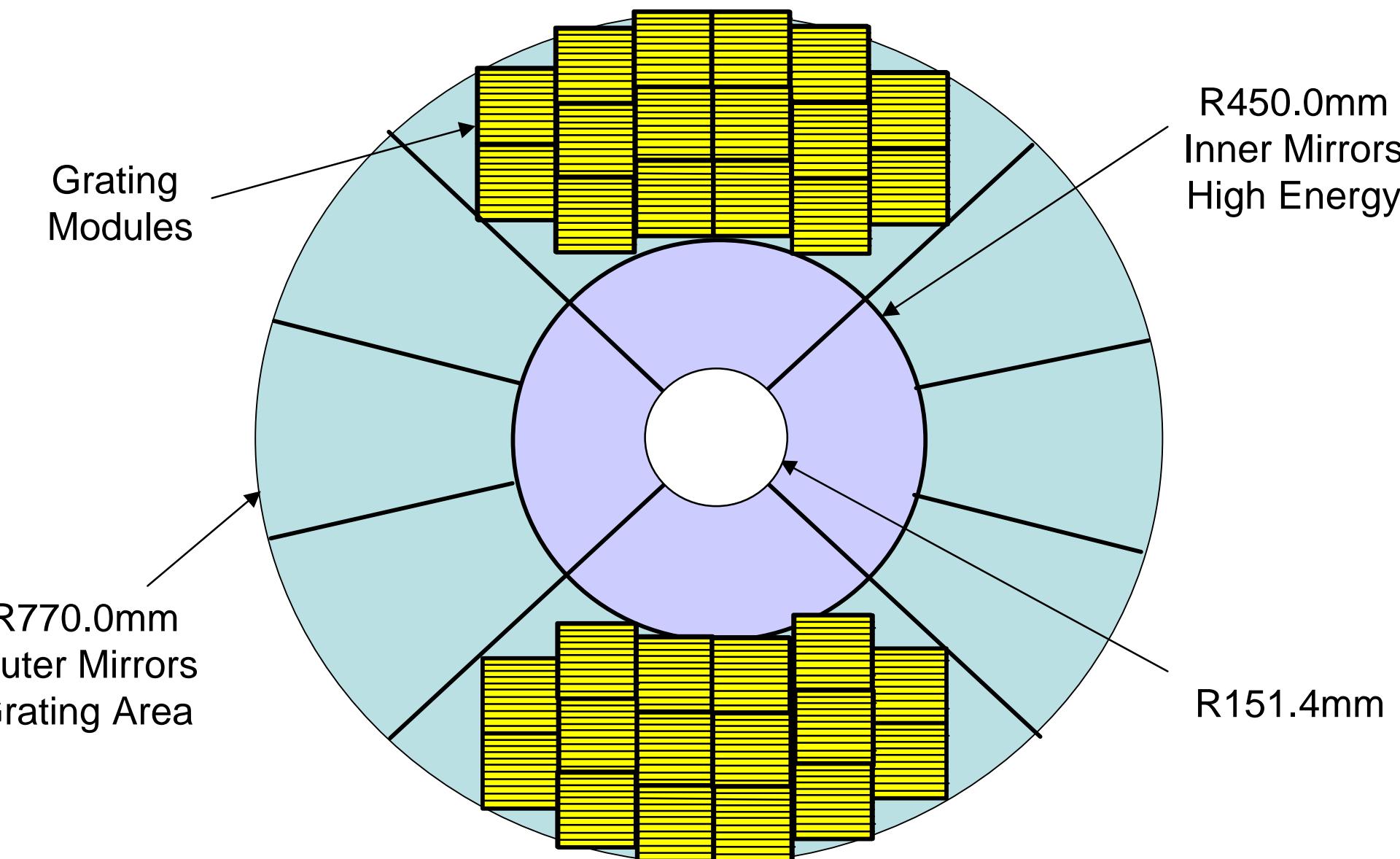


Data from a radial grating in the
off-plane mount, Wilkinson

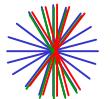
Subaperture Effect



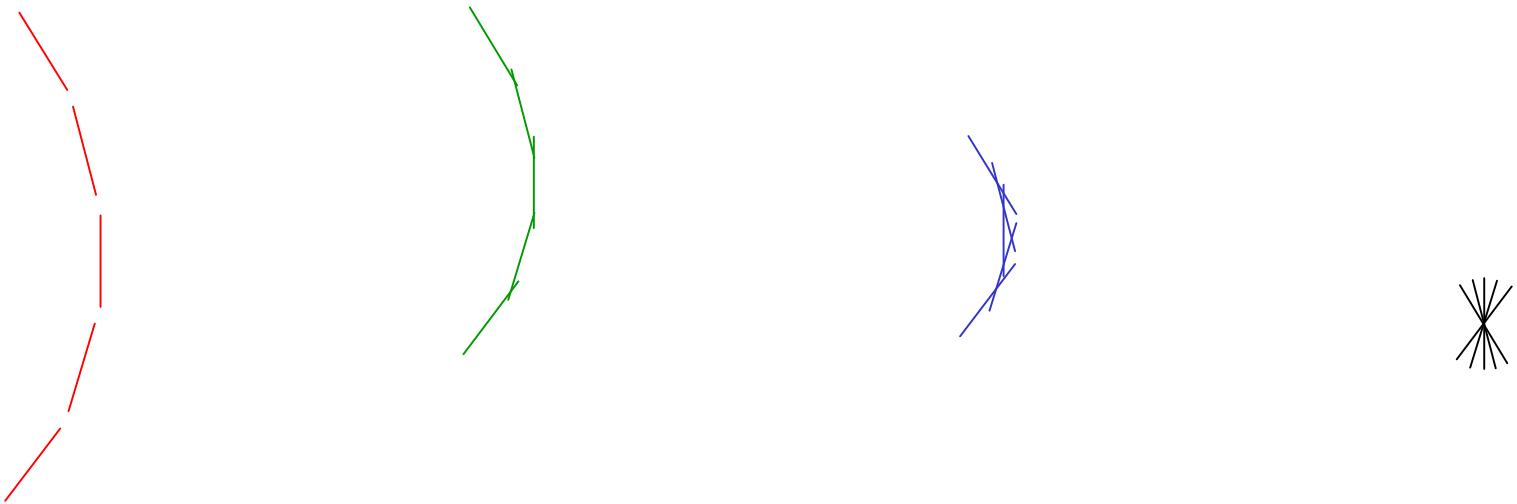
Off-plane Grating Module Locations on Envelope



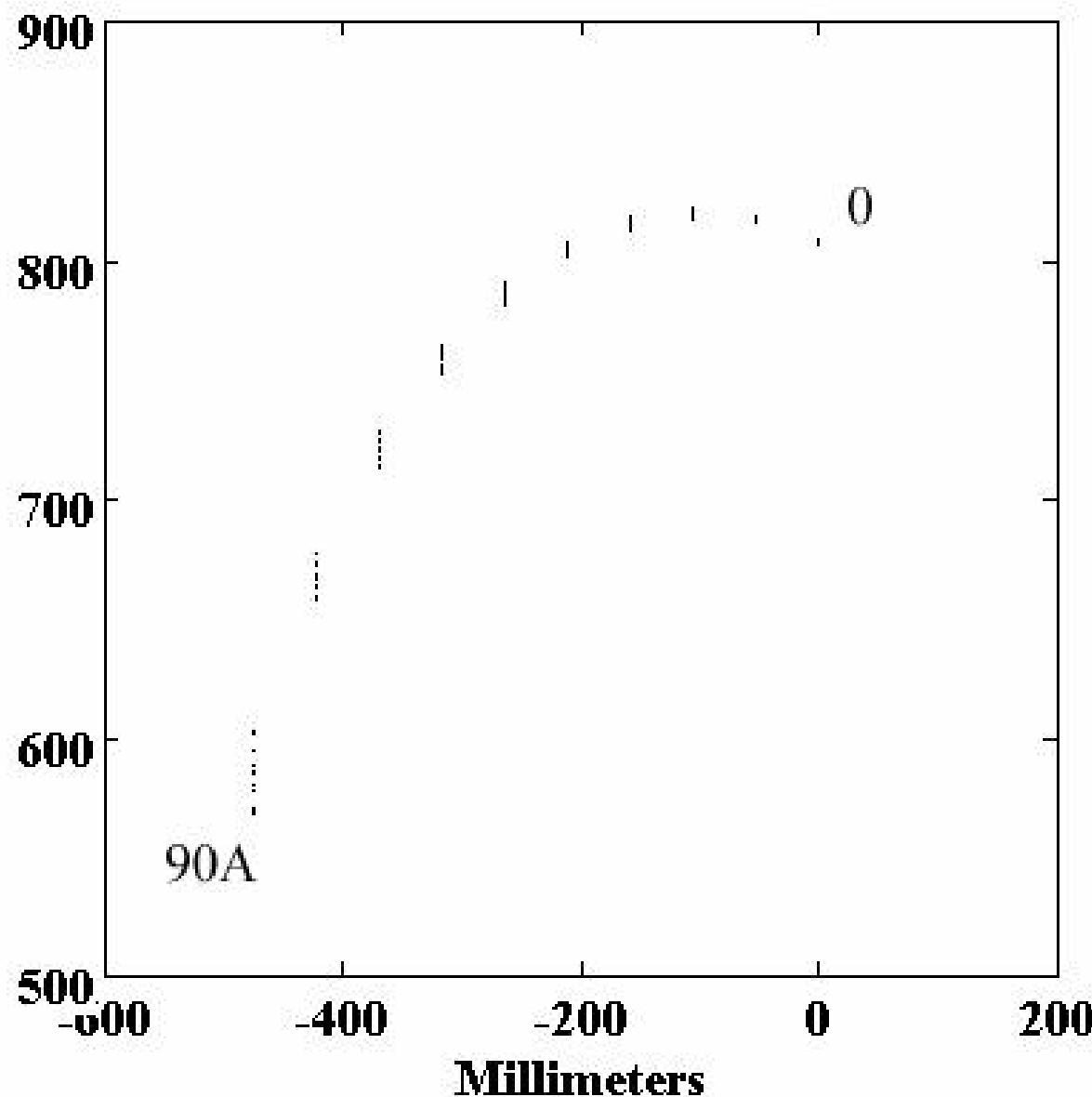
Can Improve Performance



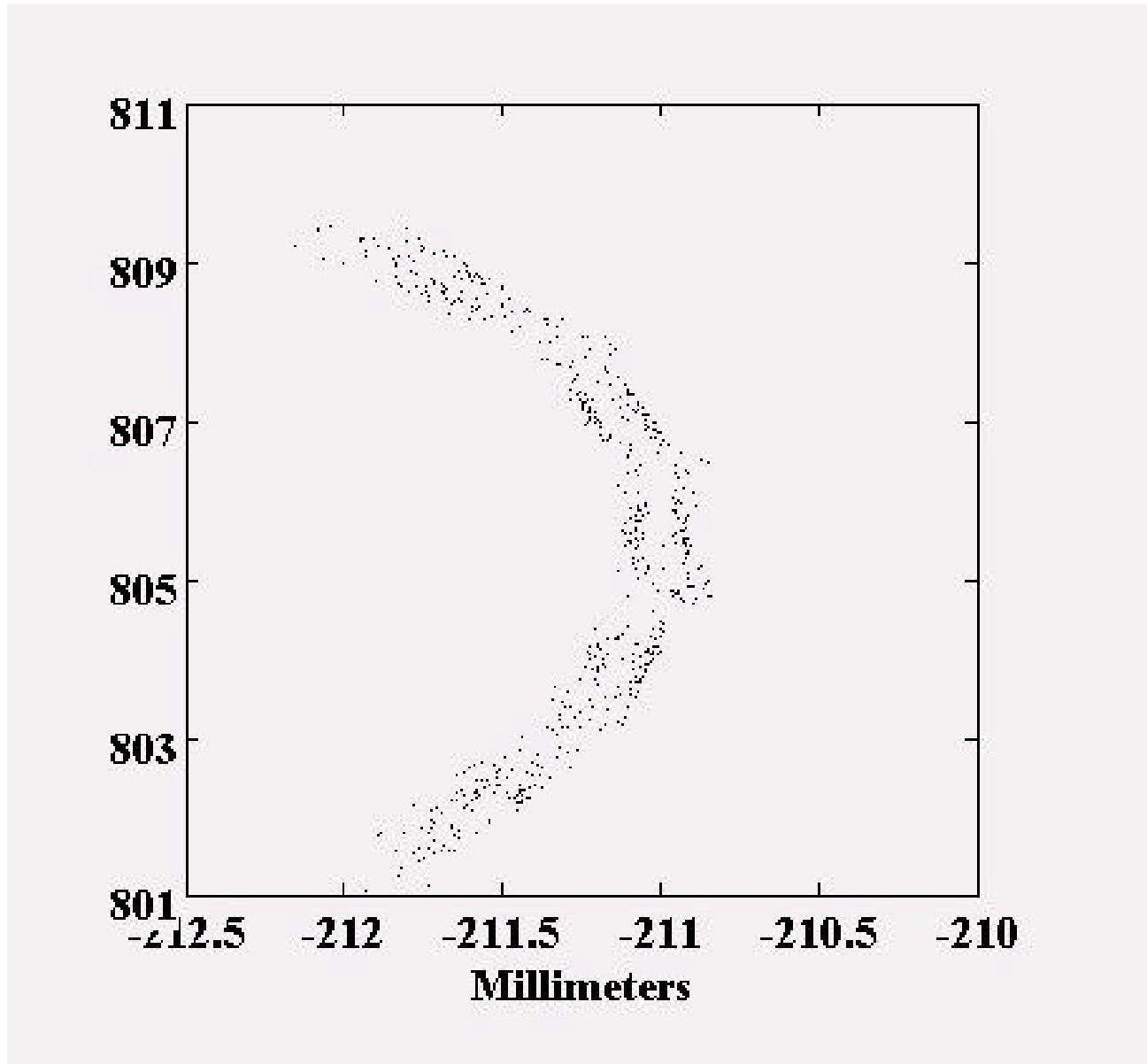
Can Improve Performance



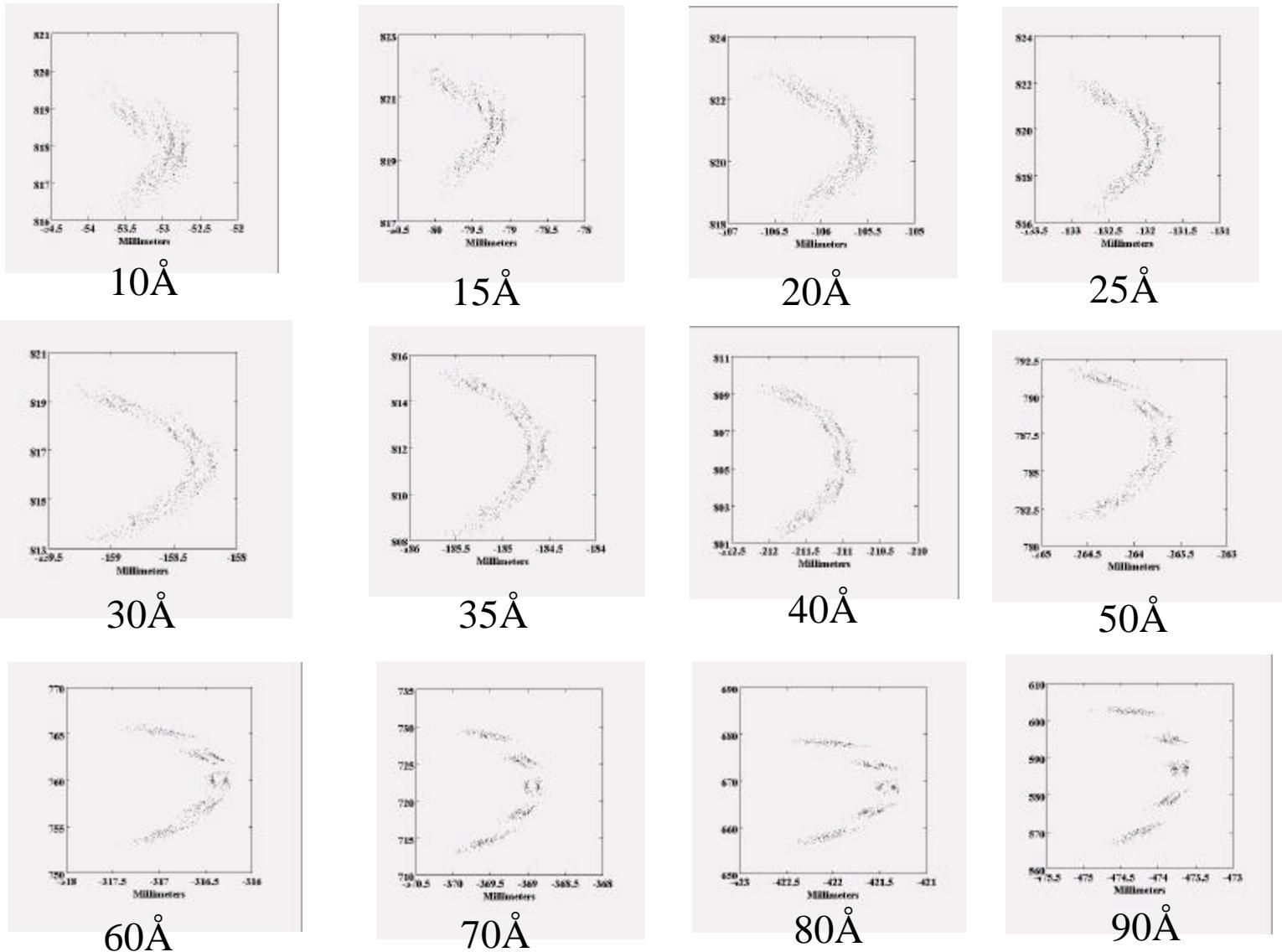
Raytracing – Arc of Diffraction



Raytrace – 35 & 35.028Å



Raytracing of Wavelength Pairs λ and $\lambda + .028\text{\AA}$



Difficulties of High Resolution $(\lambda/\Delta\lambda > 1200)$

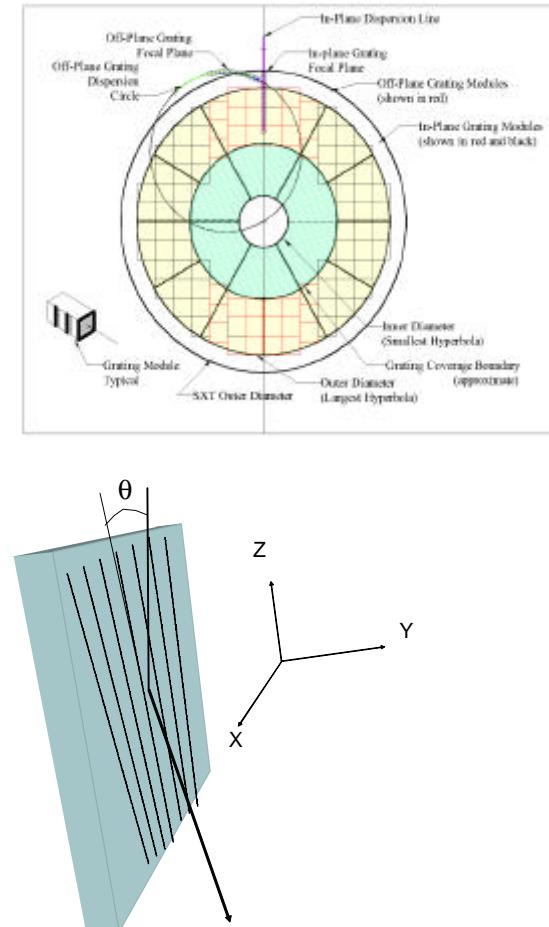
- flatter gratings
- tighter alignment
- tighter focus
- telescope depth of focus adjustment
- zero order monitor essential to aspect solution
- more difficult calibration
- greater astigmatism
 - higher background
 - more source overlap

Tolerances

Constellation X Off-plane Grating Tolerances

10/21/2003

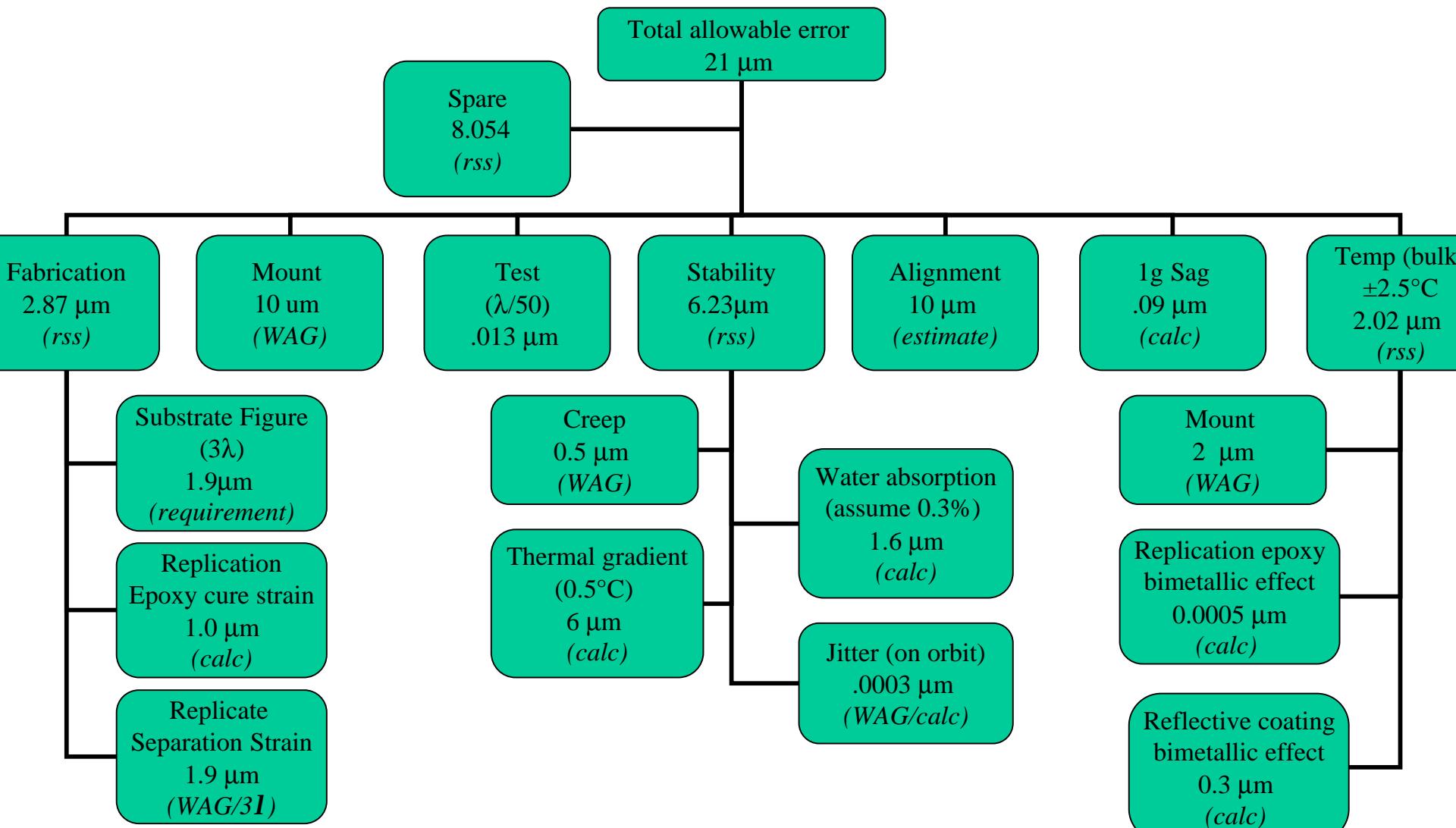
Error Type	Zero-order Allowable Tolerances			Spectrum Allowable Tolerances		
	Equation	ϵ	Grating Res = 3000	Equation	ϵ	Grating Res = 3000
Pitch Slope error	$z < \frac{ew}{2}$	0.3	2.25 arcsec	$z < \frac{eds}{F \sin y} \text{ and } z < \frac{es}{F}$	0.3	0.78 arcsec
Pitch Surface error	$d < \frac{ewh}{8n}$	0.3	0.27 μm	$d < \frac{eds w}{4nF \sin y} \text{ and } d < \frac{esw}{4nF}$	0.3	0.10 μm
Roll Slope error	$z < \frac{ew}{2 \sin q}$	0.3	64.5 arcsec	$z < \frac{eds}{2F \sin q}$	0.3	5.6 arcsec
Roll Surface error	$d < \frac{eww}{8n \sin q}$	0.3	8.6 μm	$d < \frac{eds w}{8nF \sin q}$	0.3	0.75 μm
δ_x	$d_x < ew$	0.1	(up to 11mm) Set at 1mm	$d_x < \frac{eF \sin q}{R \sin y}$	0.3	66.3 μm
δ_y	$d_y < \frac{ewF}{2 \cos q}$	0.1	33.8 μm	$d_y < \frac{eds}{\sin y} \text{ and } d_y < es$	0.3	36.0 μm
δ_z	$d_z < eh$	0.1	(up to 11mm) Set at 1mm	$d_z < \frac{eF}{R}$	0.3	0.95 mm
ϕ_x (pitch)	$f_x < \frac{ew}{2}$	0.1	0.75 arcsec	$f_x < \frac{eds}{F \sin y} \text{ and } f_x < \frac{es}{F}$	0.3	0.78 arcsec
ϕ_y (yaw)	$f_y < \frac{2ew}{h}$	0.1	27.2 arcsec	$f_y < \frac{e \sin q}{R \sin y}$	0.3	1.4 arcsec
ϕ_z (roll)	$f_z < \frac{ew}{2 \sin q}$	0.1	21.5 arcsec	$f_z < \frac{eds}{2F \sin q}$	0.3	5.6 arcsec



Where d = allowable linear error, f = allowable angular error, w = telescope resolution, q = graze angle, e = fractional limit, n = # of waves in surface error, w = grating width, h = grating height, and F = distance from gratings to detector, R = resolution (l/dl), s = telescope spot size, ds = sub-apertured image width, y = azimuthal position of grating on telescope.

Quantified tolerances assume: $w=15\text{arcsec}$, $q=2^\circ$, $w=h=110\text{mm}$, $n=1$, $F=9.5\text{m}$, $s=750\mu\text{m}$, $ds=60\mu\text{m}$, $y=30^\circ$

Wavefront Error: Resolution 1000



Off-Plane Lab Demonstrations

- ? Efficiency
 - Holographic Grating
 - Ion-etched blaze
- ? Resolution
 - Sub-aperture
 - Holographic coma control

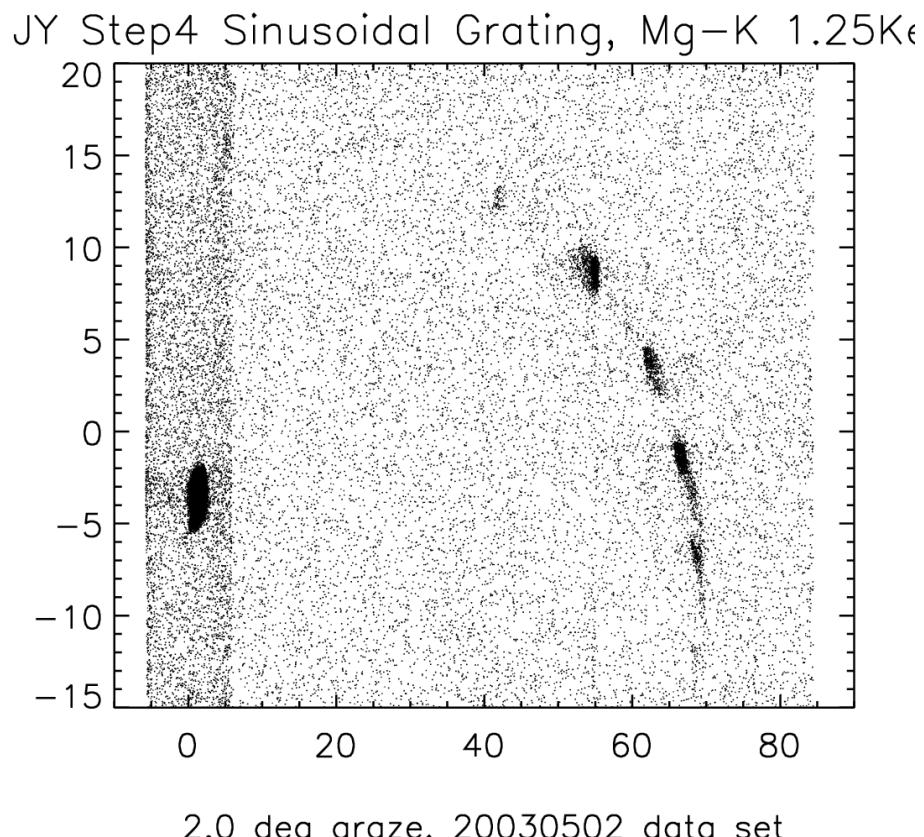
Efficiency Testing

Facility Used for COS and FUSE



Grating #1

- Jobin-Yvon, radial grooves, 4246 g/mm, unblazed

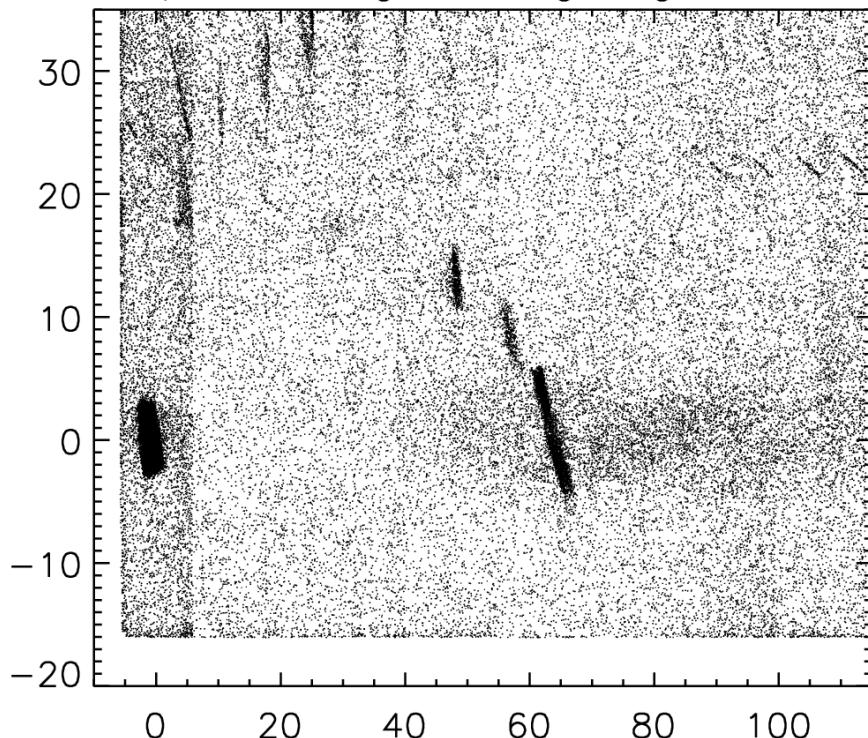


@ $\theta = 2^\circ$ Absolute
Efficiency:
strongest order = 13%
Sum orders = 29%

Grating #2

- Jobin-Yvon, radial grooves, 4246 g/mm, blazed 13°

JY Step4 13 deg Grating, Mg-K 1.25KeV



2.0 dea araze. 20030428 data set

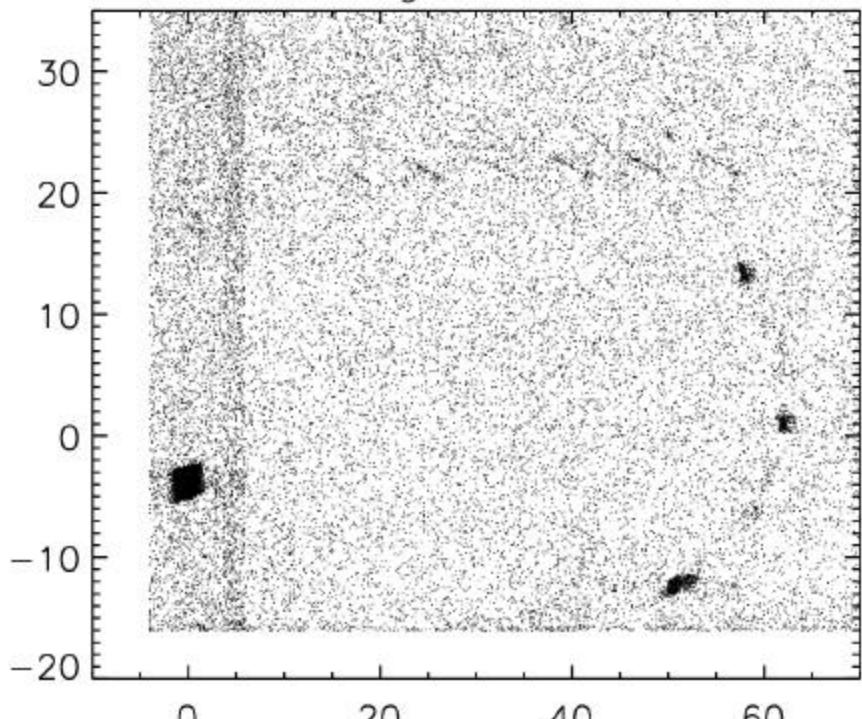
@ ? = 2° Absolute Efficiency:
strongest order = 6.4%

Sum orders = 11%

30% (w/ scatter)

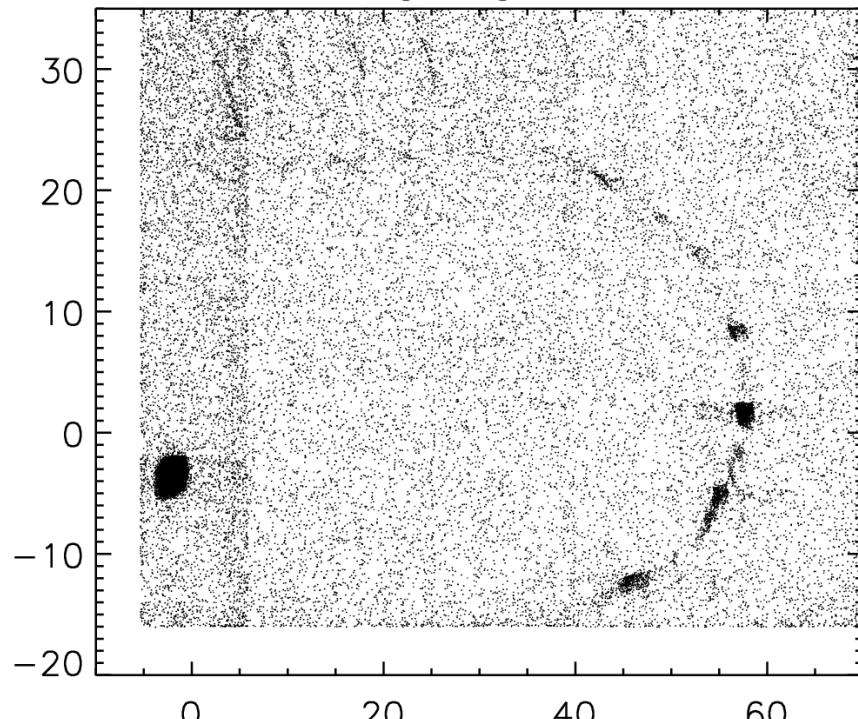
Grating #3

MIT Grating, Cu-L 0.93KeV



2.0 dea araze. 20030501 data set

MIT Grating, Mg-K 1.25KeV



2.0 dea araze. 20030501 data set

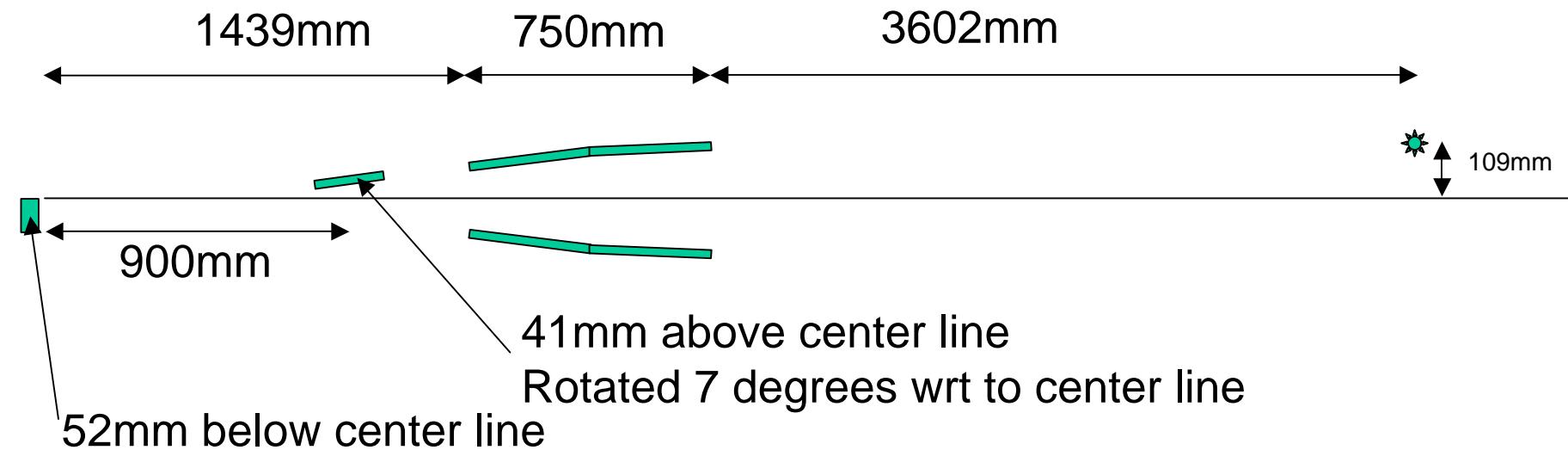
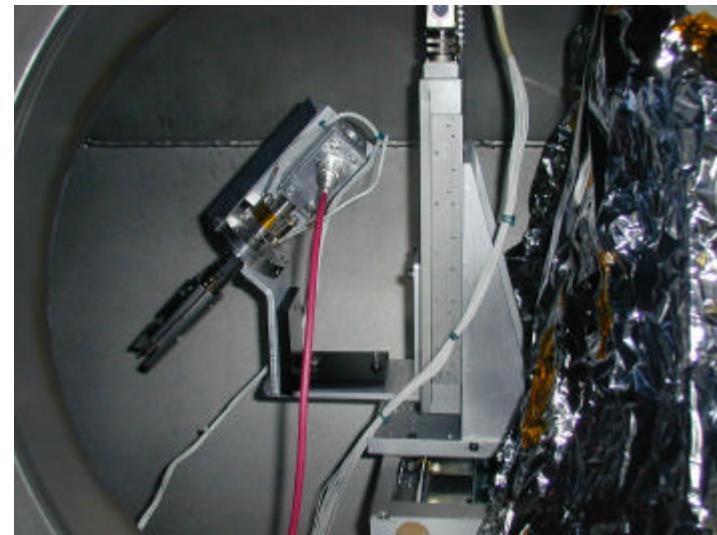
Grating #3

? MIT, parallel rulings, 5000 g/mm, blazed 7°

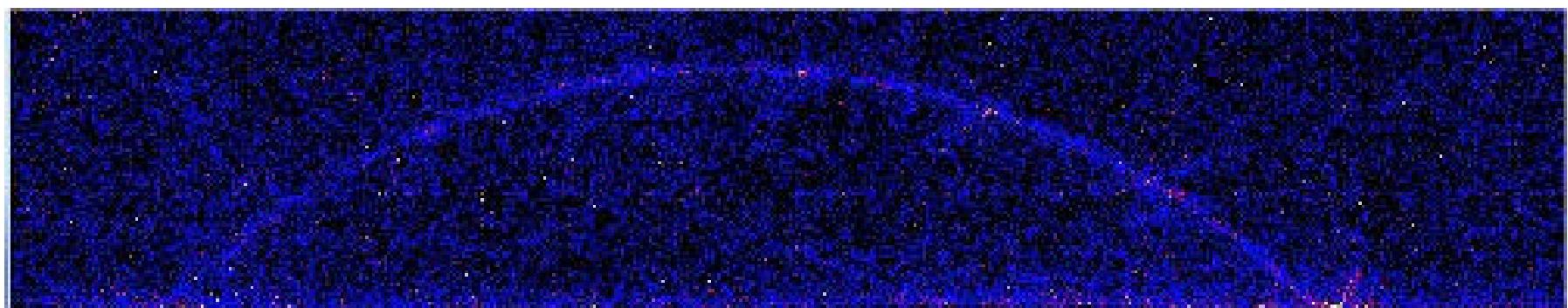
	?	Abs. Eff. one order	Abs. Eff. Sum orders	Groove Eff.*
Mg-K (1.25 keV)	1.35	25%	38%	54%
	1.5	28%	40%	59%
	2	9%	27%	48%
Cu-L (0.93 keV)	1.5	21%	24%**	35%**
	2	18%	30%	45%

Groove eff. = Abs. eff./Reflectivity (a.k.a. Relative eff.)

Resolution Testing

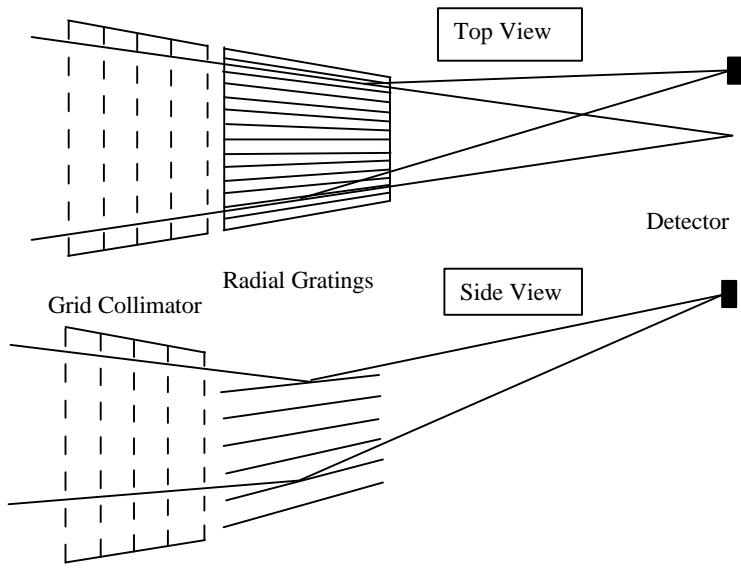


Resolution of 500



Limited by telescope (dispersion limited):
3mm image from hole telescope
0.2mm image subapertured
1m focal length

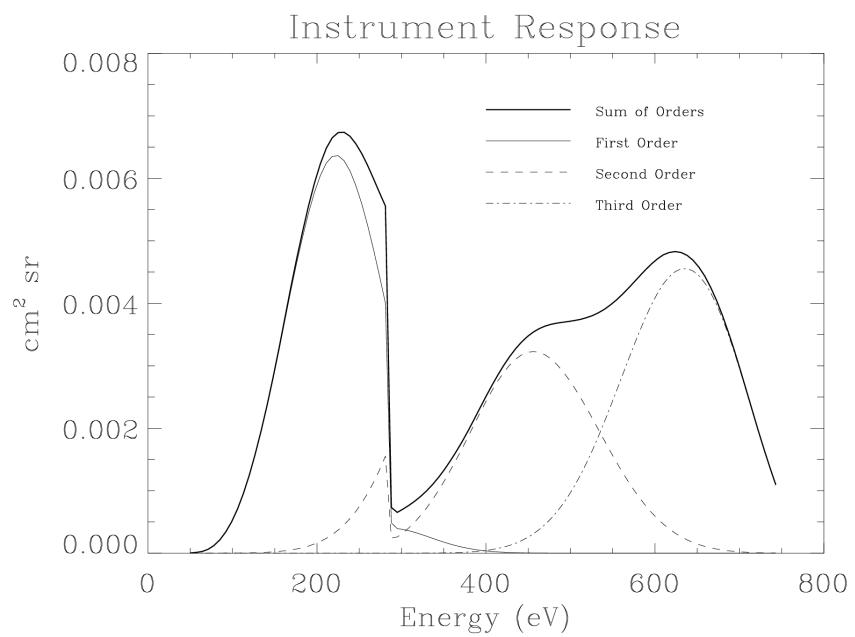
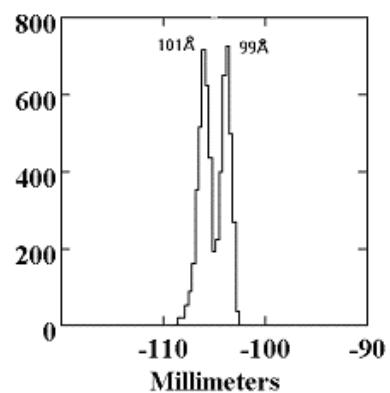
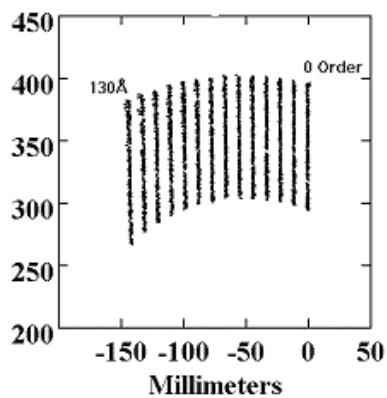
Off-plane Flight Demonstration New Sounding Rocket Program



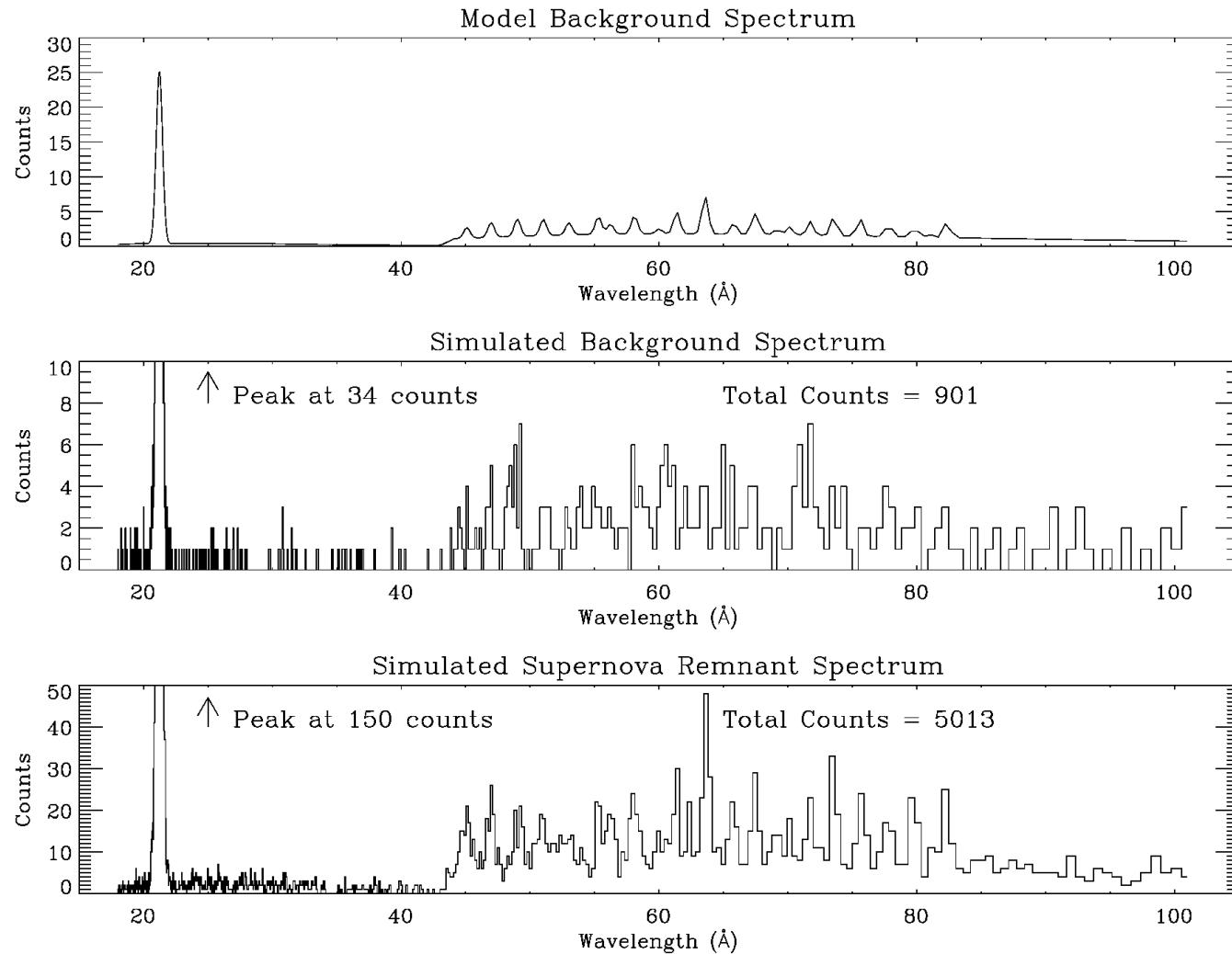
Spectroscopy of Highly
Extended X-ray Sources
 $\lambda/\delta\lambda \sim 100$

SNR
Superbubbles
Soft X-ray Background

Performance

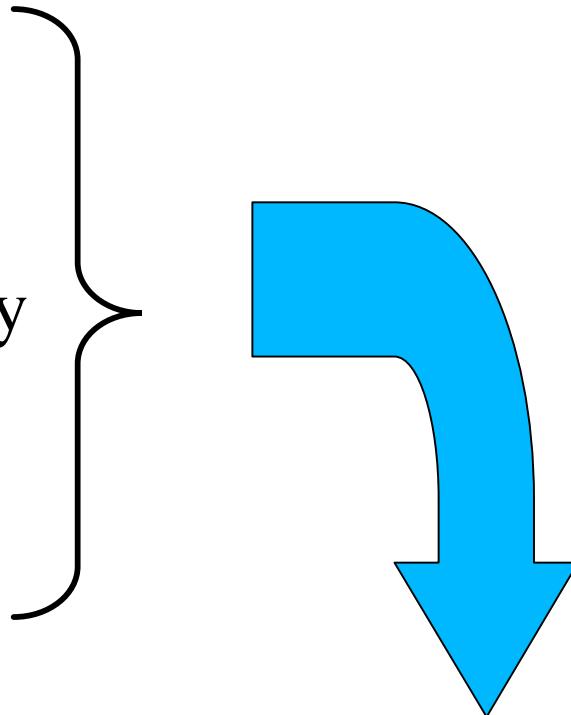


Expected Results

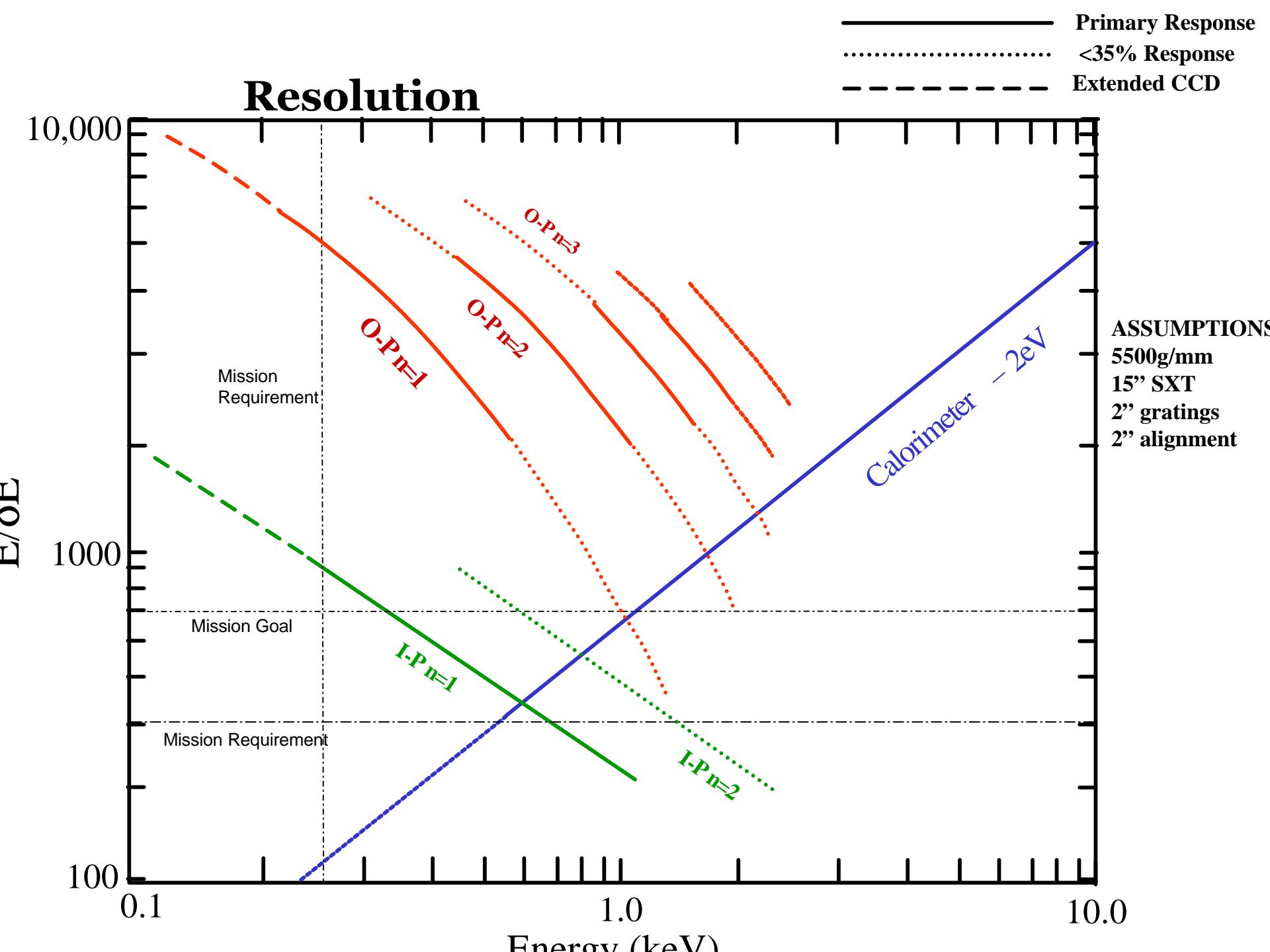


Off-Plane Potential

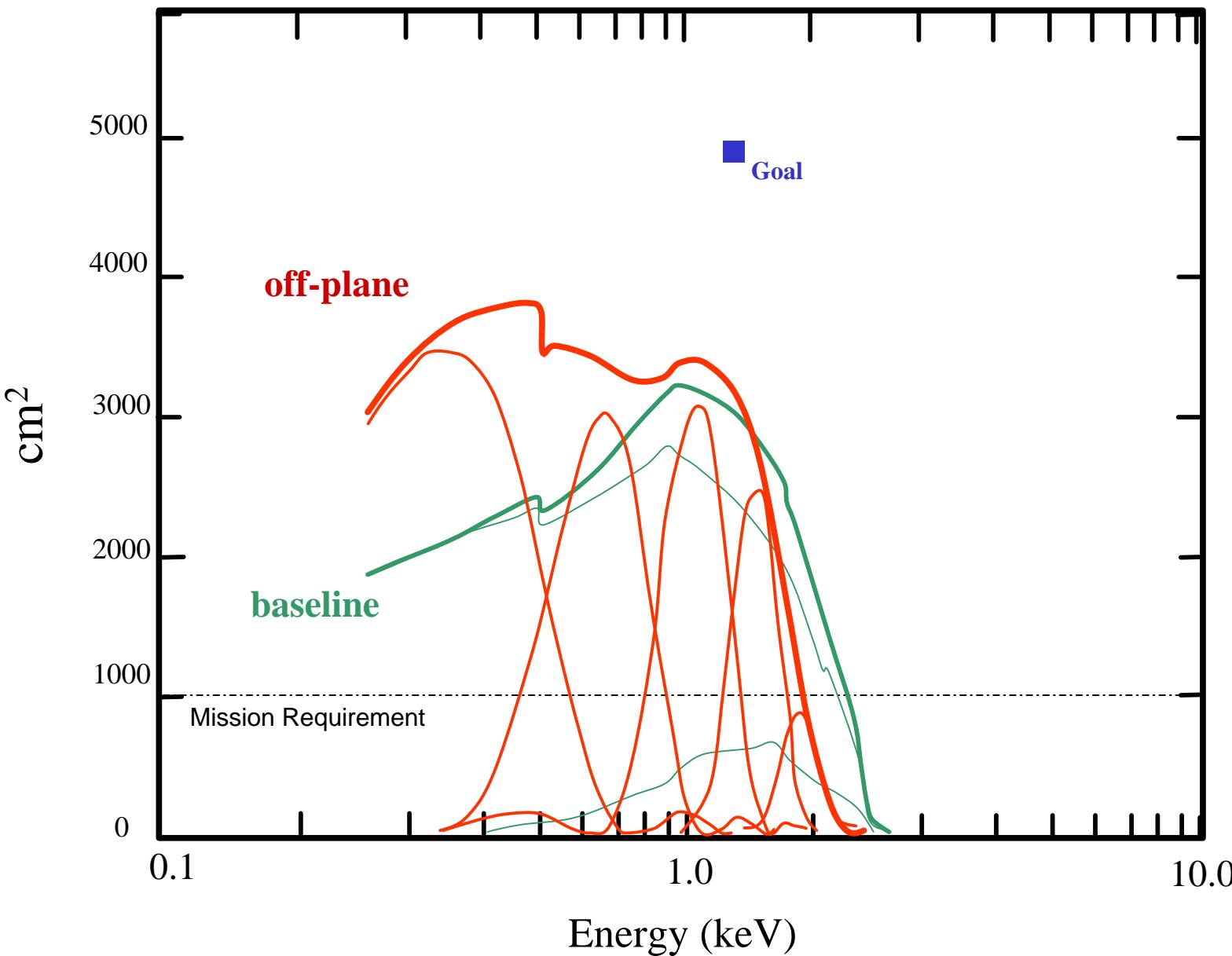
- ? Higher Resolution
- ? Higher Collecting Area
- ? Spectro-photo-polarimetry
- ? Lower Cost
- ? Lower Mass



Some Combination of These



Effective Area



ASSUMPTIONS:

- Coverage 40% of outer envelop
- Off-Plane Groove Efficiency 80% of theoretical
- 85% Structure Transmission
- CCD thin Al filter only

Cost/Risk Curve

Difficult (\$\$\$)
Moderate (\$\$)
Easy (\$)

